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Earthworms and soil remediation: liming of acidic coniferous forest soils in Southern Sweden

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Summary. In a coniferous forest area exposed to airborne acidification in S. Sweden, two pairs of similar habitats (two mature forests, two reafforested sites) were selected for a soil remediation programme. One site of each pair was limed in May 1985. In addition to the effects of liming on soil chemistry, vegetational and soil fauna changes were followed. Lumbricids were sampled prior to liming and three and seven years afterwards. The first sampling showed that the sites had a 'one-species community' (*Dendrobaena octaedra*), though natural coniferous forest soils in S. Sweden often are inhabited by 3–4 species. The later samplings did not reveal any marked responses of lumbricids to liming. Neither biomass and density nor species numbers increased significantly over time. Though some few *Dendrodrilus rubidus* appeared at sampling after liming, the dominant species was still *D. octaedra*. Field experiments with netbags showed that both *Lumbricus rubellus* and *D. rubidus* were able to survive 1–2 winters in the forest soils, independent of treatment. In relation to the size of the limed sites and the duration of the study, the dispersal and colonization abilities of the lumbricid species commonly found in coniferous forest soil are not high enough to affect the community parameters chosen. It is suggested that a soil remediation programme should include inoculation of specimens sampled in nearby, similar habitats to support a rapid and successful colonization of earthworms.

Key words: *Dendrobaena octaedra*, *Dendrodrilus rubidus*, *Lumbricus rubellus*, soil acidification, liming, coniferous forest soil, netbag experiments

Introduction

Soil acidification has become a main cause for environmental concern in northern Europe. The pH of the humus layer of forest soils in S. Sweden has decreased markedly over the last 30–35 years (Falkengren-Grerup 1987) due to long-range airborne acidifying pollutants (SO_x and NO_x). The gradual acidification has resulted in changed plant communities, reflected for instance in the field layer of deciduous forests (Falkengren-Grerup 1986). Field experiments have shown that simulated acid precipitation has an evident impact on the abundance, biomass, and diversity of the soil fauna and it has been concluded that even short-term continuous acidification leads to significant community changes (Lundkvist 1977; Bååth et al. 1980; Hågvar & Amundsen, 1981; Hågvar 1984; Huhta 1984). To arrest and, if possible, counteract increasing acidification of forest soils and ultimately increase the primary productivity, some Swedish coniferous stands were limed as early as the beginning of the 20th century (Nihlgård et al. 1988) – a programme that unfortunately did not pay any attention to soil fauna. Later field experiments in Nordic coniferous forests have focussed on the responses of microarthropods and earthworms to fertilizers such as lime and ashes and to patches of deciduous stands maintained (Huhta 1979; Bååth et al. 1980; Huhta et al. 1983; Persson et al. 1987).

Though lumbricid earthworms seldom are very abundant in Nordic coniferous forest soils (Nordström & Rundgren 1973; Terhivuo 1989), their role in decomposition processes may be substantial (Haimi & Huhta 1990). In addition to the two infrequently occurring species, *Lumbricus rubellus* Hoffm. and *Aporrectodea caliginosa* (Sav.), *Dendrobaena octaedra* (Sav.) and *Dendrodrilus rubidus* (Sav.) predominate in Nordic podzolic and degrading forest soils, as reported for Denmark (Bornebusch 1930), Norway (Abrahamsen 1972), Sweden (Nordström & Rundgren 1973), Iceland (Bengtson et al. 1975), the Faroe Islands (Enckell & Rundgren 1983), and Finland (Terhivuo 1989). Most earthworm species that inhabit naturally acid forest soils complete their life-time in the litter and mor horizons, and hence will be exposed to pollutants hitting the soil surface. Therefore, they would presumably also respond promptly to soil improving measures such as liming, if an elevated soil pH were the only factor determining the occurrence and growth rate of lumbricid populations.
A research programme was launched in 1984 to establish the impact of liming on acidified coniferous forest soil and to monitor changes in soil structure, soil chemistry, flora and fauna (Nihlgård & Pålsson 1988). A minor part of the programme was addressed to studies on the recovery of selected groups of soil fauna, of which the study on earthworms is reported on here. It was hypothesized that amelioration would affect density and species number of lumbricids, since acid-tolerant and ubiquitous (*sensu* Satchell 1955) earthworm species should especially respond positively to the enhanced pH-values. The study was conventionally based on field surveys focussing on lumbricid community parameters such as density, biomass, and species composition, before liming and three years afterwards. It was also assumed that the incorporation of granulated lime and its uptake by plants involve such slow processes that an improved quality of the leaf litter would not be reflected in the lumbricid community within three years but after a longer period of time. A complementary sampling was therefore undertaken seven years after liming. The field survey was combined with netbag experiments to confirm whether *L. rubellus* and *D. rubidus* could survive in unlimed soils of the area and whether the latter species would respond to liming by increased survival and population growth. A pilot experiment on simulated immigration of *D. rubidus* was also carried out.

Materials and Methods

Study sites

The study area was situated in S. Sweden (province of Blekinge), 20 km N. of the town of Karlshamn, where the coastal strip of farmland and deciduous woods merges into a coniferous forest dominated by Norway spruce and pine trees intermingled with birch, mountain-ash, and alder. Four sites were chosen for the study, each surrounding a small lake and thus constituting separate minor watersheds. Two sites (A: Stora Krokgylet; B: Lilla Krokgylet) were mature conifer forest (80 – 100 years old) with a field layer dominated by *Vaccinium myrtillus* and *Deschampsia flexuosa*. When the study period started the remaining sites (C: Matgylet; D: Trehörnagylet) had been reafforested and the spruce trees were less than 10 years old. The high flux of solar radiation had stimulated the field layer dominated by *D. flexuosa* and *Calluna vulgaris* to spread and flower vigorously. Young birch trees had taken root at the start of the study, but were thinned out between the second and third sampling occasions.
The pH-values of the mor layers were low before liming (Table 1). The contents of available calcium were similar in sites forming the pairs. Two kinds of lime were applied in May 1985. Site B was limed with granulated, converted slag (5000 kg ha^{-1}) spread from a helicopter. Similarly applied dolomite lime (5000 kg ha^{-1}) was used to amend the reafforested site D. By 1989 the pH-values and contents of available calcium of limed sites had increased in the mor layers but hardly at all in deeper layers.

Sampling and preservation

Earthworm populations were estimated using the formaldehyde method (Raw 1959). The method has some obvious disadvantages, especially at periods of low earthworm activity. However, in the coniferous

Table 1. pH_{KCl} and available calcium in the mor and mineral horizons of four coniferous forest sites in S. Sweden. Two sites were limed in 1985 by applying converted slag (site B) and dolomite lime (site D)

Site	Type of forest	Treat-ment	Year of sampling	Mor soil		Mineral soil	
				pH*	Ca^{2+}**	pH*	Ca^{2+}**
A	mature		1984	2.83	0.10 ± 0.02	4.08	13.0 ± 3.50
			1989	3.07	0.44 ± 0.02	3.07	8.46 ± 4.68
B	mature	limed	1984	2.79	0.14 ± 0.01	4.04	12.0 ± 0.70
			1989	3.99	2.49 ± 0.52	3.99	6.52 ± 0.18
C	reaffor.		1984	3.32	0.25 ± 0.07	3.97	57.0 ± 21.0
			1989	2.63	0.17 ± 0.01	4.10	9.14 ± 1.99
D	reaffor.	limed	1984	3.07	0.26 ± 0.03	4.00	28.0 ± 10.6
			1989	4.48	1.86 ± 0.25	4.44	36.6 ± 9.07

* extracted in 1.0 M KCl (vol: vol 1 : 1); B. Fransman and B. Nihlgård, unpubl.
** Ca^{2+} (mg g^{-1} dry mass) after extraction in 0.14 M NH_4Ac (pH 4.8) for 2 h (n = 2); B. Fransman and B. Nihlgård, unpubl.

forests under study, where low population densities were to be expected (affects the soil volume sampled), passable tracks were distant and water was available nearby the formaldehyde method was preferred to methods such as handsorting and heat extraction, which require access to laboratory facilities.

On each sampling occasion fifteen squares (0.5 m^2) were sampled. They were laid out haphazardly and 2–4 m apart within a central area ($\approx 400\,m^2$) of each site. Sampling was carried out in October when daily mean air temperature was 5–10 °C and hence the worms were still highly active.

Specimens obtained were killed and fixed in 50% ethanol and preserved in 80% ethanol. Biomass was determined after 3–4 weeks of preservation and was defined as the weight of the worms in a sampled square after drying on filter paper for 1 min. For weight losses due to preservation, see Satchell (1969).

Netbag experiments

The success (survival and reproduction) of founder units of *L. rubellus* in unlimed soil was followed using netbags. Housing earthworms in netbags under field and laboratory conditions has resulted in adequate survival of the founder units of *A. caliginosa* (Bengtson et al. 1979) and *Lumbricus terrestris* L. (Bengtsson and Rundgren 1992), but somewhat lower survival of *L. rubellus* than expected (Bengtson et al. 1979). Difficulties in maintaining *L. rubellus* in microcosms are also evident from the studies of Haimi & Huhta (1990) and Haimi & Boucelham (1991). To determine whether the survival of founder units depends on the shape of the enclosure two types of netbags were tested. Besides the one previously used by Bengtson et al. (1979) and Bengtsson & Rundgren (1992) (diameter 100 mm, depth 150 mm, mesh size 475 µm) (here referred to as type I), another 'netbag' or container (type II) was constructed to facilitate both vertical and horizontal burrowing of *L. rubellus* (Fig. 1). It was made of a plastic pipe (diam. 110 mm, length 500 mm), the ends of which were sealed with nets (mesh 475 µm). Three minor bags (diam. 50 mm, depth 150 mm, mesh 475 µm) were attached to the pipe.

Needle litter, mor and mineral soil sampled in the mature forest (site A) were deep-frozen (−30 °C) and thawed (3–4 days) three times to reduce indigenous soil fauna. Conventional netbags (type I), were filled with needle litter, mor and mineral soil in separate layers, corresponding to the soil profile *in situ*. The pipes of the container (type II) were provided with a layer of needle litter (thickness 5–6 cm) and attached bags with mor and mineral soil as for type I. Adults of *L. rubellus* were collected in a deciduous forest E. of Lund, S. Sweden (Nordström & Rundgren 1973; loc. 12) using the formaldehyde method (Raw 1959). Sampled individuals were immediately washed in water and placed on top of soil in a bucket. Only specimens that by the next morning had succeeded in burrowing into the soil were used for the experiment. Each netbag was inoculated with three specimens and then sealed. Ten netbags of each kind were dug into the soil at site A in November so that inner and outer soil layers corresponded and were in close contact. Survival and production of cocoons and offspring were checked the following June. The bags were brought to the laboratory and stored at 6 °C and the soil was carefully handsorted within a week.

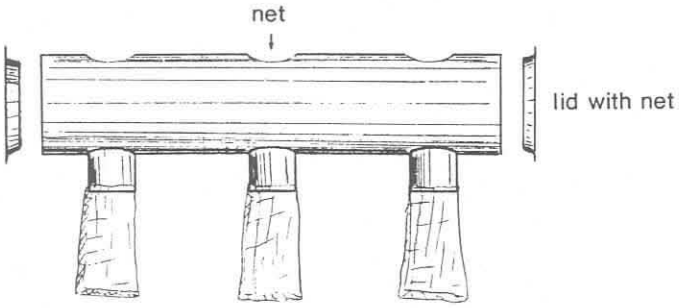

Fig. 1. The container type earthworm enclosure. Ends of the 500 mm long plastic pipe and holes for the entry of precipitation on top were sealed with nets. Three minor bags were attached to the pipe. Mesh size of all nets was 475 µm

Netbags (type I) were also used to follow the performance of *D. rubidus* in the mature forest sites (A and B). All bags were filled with soil (needle litter, mor, mineral soil) originating from the site where they were to be placed. Four adult *D. rubidus* were inoculated into each bag before sealing. The worms had been sampled by hand in a pine forest E. of Lund, S. Sweden (Nordström & Rundgren 1973; loc. 11). The filled bags were handled in the same manner as for *L. rubellus* above. Three series of bags were used to follow the success (survival, reproduction) of founder units:
1) in unlimed (site A) and limed (site B) soil, respectively;
2) in soil ameliorated with deciduous litter;
3) after simulated immigration.
Newly fallen birch leaves were picked on the surface floor at the edge of the mature forest (A). They were washed in tap water to remove soil fauna. 20–30 leaves were placed on top of the needle litter layer of bags of series 2. Immigration was simulated by adding one adult and one juvenile *D. rubidus* in May following the first winter. The number of netbags used in each series and the starting and destructive sampling dates are given in Table 4.

Results

The earthworm biomass of the two mature forest plots did not differ before liming (one-way ANOVA, $F = 3.074$, $p = 0.123$) (Table 2). After liming the difference in biomass was still insignificant both in 1987 and in 1991. On the first sampling occasion the lumbricid biomass in the reafforested site (D) was higher than in site C (one-way ANOVA, $F = 11.176$, $p = 0.003$). After liming, in 1987 the difference remained (one-way ANOVA, $F = 5.484$, $p = 0.0291$). Similar differences were reflected in the figures of total density in sites C and D (one-way ANOVA, $F = 10.573$, $p = 0.0043$ and $F = 5.973$, $p = 0.0239$, respectively), whereas the total density figures in sites A and B did not differ on any sampling occasion.
Liming did not significantly increase either biomass or density in the mature forest or the reafforested one over time. No worms were obtained in site C in 1991, a year when the autumn followed upon a dry summer. Throughout, density figures were lower in 1991 than in 1987, which draws the attention to the need for long-term studies addressing natural population fluctuations to understand anthropogenic influences on soil fauna.
D. octaedra was the only species sampled in 1984 (Table 2). A few *D. rubidus* occurred in the limed site D in 1987 and 1991 and a few *L. rubellus* in the unlimed site A in 1987. There was no clear difference in the ratios of adult: juvenile *D. octaedra* in the mature forest sites over the period, but a tendency towards more juveniles per adult in the limed reafforested site (D) was evident on the last sampling occasion.
Approximately 27% of adult *L. rubellus* survived the winter in the twenty netbags (Table 3). A few more survivors were found in the container type (II) than in the conventional netbag (I), but the difference was not significant. In nine out of the twenty enclosures the founder units had become extinct, i.e. none of the inoculated adults were alive. If the

Table 2. Biomass (g m^{-2}) and density (ind m^{-2}) of lumbricid earthworms in four coniferous forest soils, S. Sweden. Two of the sites (B and D) were subject to liming in 1985. Mean (n = 15) and standard deviations are given

Site	Forest type	Treatment in 1985	Sampling year	Biomass g m^{-2}	Density (ind m^{-2})					Ratio ad: juv *D. octaedra*
					Total	*D. octaedra*		*D. rubidus*	*L. rubellus*	
						ad	juv			
A	mature, 80–100 yrs		1984	0.48 ± 0.72	6.1 ± 9.9	1.6 ± 2.5	4.5 ± 8.4			0.36
			1987	0.80 ± 1.12	5.3 ± 5.8	2.7 ± 3.9	2.1 ± 3.0		0.5 ± 1.4	1.29
			1991	0.39 ± 0.52	4.3 ± 5.9	2.1 ± 3.7	2.1 ± 4.0			1.00
B	mature, 80–100 yrs	limed	1984	0.08 ± 0.20	0.8 ± 1.6	0.3 ± 1.0	0.5 ± 1.4			0.60
			1987	0.32 ± 0.48	4.5 ± 7.1	1.3 ± 2.5	3.2 ± 5.7			0.41
			1991	0.20 ± 0.32	2.9 ± 5.8	1.6 ± 3.0	1.3 ± 3.3			1.23
C	reaffor., <10 yrs		1984	0.20 ± 0.20	2.9 ± 3.2	0.8 ± 1.6	2.1 ± 2.6			0.38
			1987	0.20 ± 0.24	4.0 ± 3.7	0.5 ± 2.1	3.5 ± 3.7			0.14
			1991	0	0					
D	reaffor., <10 yrs	limed	1984	1.28 ± 1.96	17.0 ± 26.2	6.9 ± 10.7	10.1 ± 16.3			0.68
			1987	1.20 ± 1.36	16.8 ± 16.2	5.3 ± 5.8	10.1 ± 9.0	1.3 ± 4.2		0.52
			1991	0.32 ± 0.38	6.4 ± 5.8	0.5 ± 1.4	5.3 ± 5.2	0.5 ± 1.4		0.09

Table 3. Development of founder units of *L. rubellus* inoculated in two different types of netbags tested in a mature forest soil (site A). For a description of the different bags, see Methods. Three adult worms were inoculated in early November 1986 and the experiment lasted until June 1987

Type of netbag	Number of netbags	Population size in June 1987 (ind bag^{-1})		
		adults	subad + juv.	cocoons
Conventional (I)	10	0.5 ± 0.5	1.4 ± 1.1	0.5 ± 0.7
'Container' (II)	10	1.1 ± 1.1	1.3 ± 1.1	0.4 ± 0.7

survival of a founder unit is taken to include the presence of subadults, juveniles and cocoons as well, only two of the units completely failed to survive. Reproduction was established in all netbags but the two extinct ones, both of which were of the conventional type (I).

On all sampling occasions but one in 1987, it was found that ≧50% of the founder units of *D. rubidus* had survived the preceding winter (Table 4). Adding birch leaves or simulating immigration by adding two specimens just before the commencement of the winter period did not substantially increase the survival rate of the units. Eight out of ten units were still vigorous after two winters at site A. Reproduction, shown by production of hatchlings or cocoons, was confirmed in 56 of the 90 units. The minimum number of cocoons found in bags dug into limed or unlimed soils differed significantly on one out of three comparable occasions only; in June 1987 more cocoons were found in bags containing limed soil ($p < 0.01$).

Table 4. Survival, confirmed reproduction and population size at sampling of founder units (four adults per netbag at start) of *D. rubidus* in two different mature coniferous forest sites (site A – unlimed, site B – limed). The netbags were filled with soil and needle litter originating from the respective sites. Birch leaves were added to 20 bags and immigration was simulated by adding one adult and one juvenile *D. rubidus* to 20 bags in May 1987. The experiment started in December 1986. Dates of destructive sampling of units are given. Population size at sampling is expressed as mean and standard deviation

Site	Liming	No. bags sampled			Date of sampling	No. of founder units		Minimum population size per bag	
		needle litter	birch leaves added	simulated immigration		Surviving	Reproduction	ad-juv	no. cocoons
A	no	10			June-87	7	6	1.2 ± 1.5	0.4 ± 0.5
		10			Oct-87	7	7	0.5 ± 0.7	0.9 ± 1.3
		10			June-88	7	7	0.8 ± 0.8	2.5 ± 3.3
			10		June-87	5	4	0.3 ± 0.7	0.7 ± 1.6
			10		Oct-87	3	3	0.2 ± 0.6	0.1 ± 0.3
				10	Oct-87	8	8	0.3 ± 0.9	1.4 ± 1.3
B	yes	10			June-87	10	10	1.8 ± 1.3	5.0 ± 4.8
		10			Oct-87	7	6	0.1 ± 0.3	1.4 ± 1.6
				10	Oct-87	5	5	0.2 ± 0.4	0.7 ± 1.1

* at least one founder specimen surviving

Discussion

A main reason to select lumbricid populations for a study of the impact of liming on soil fauna is that earthworms constitute an important part of the true invertebrate biomass in most terrestrial habitats. In addition, they also promote and regulate a number of soil processes, such as decomposition. It would therefore be a goal *per se* in soil conservation to support optimum densities of lumbricid populations. At least three more reasons are worth mentioning.

First, a negative relationship has been established between soil acidity and earthworm community parameters (Bornebusch 1930; Satchell 1955; Abrahamsen 1972; Nordström & Rundgren 1974; Edwards & Lofty 1975; Standen 1979) and population parameters, such as activity (Doeksen & Wingerden 1964), growth and reproduction (Bengtsson et al. 1986). Generally, species number is low at naturally low soil pH and the overall fecundity of lumbricids is negatively affected by lowered pH.

Second, a continuous decrease in earthworm densities has been observed in field acidification experiments (Persson et al. 1987), and the lumbricid community in degrading soils gradually decreases in diversity (Nordström & Rundgren 1974; Enckell & Rundgren 1988). Thus, when a deciduous forest is turned into a coniferous plantation or a meadow is abandoned, earthworm species with high demands on soil quality will go extinct. Primarily deep burrowers (*L. terrestris*, *Allolobophora longa* Ude) will be subjected to a decrease of soil quality. Similarly, soil quality decrease in a coniferous forest soil, for instance due to acidification, will first hit species requiring high quality (within the constraints set by the coniferous forest soil), such as *A. caliginosa*. But *L. rubellus* and *D. rubidus* both of which frequently occur in coniferous forest soils of northern Europe (Abrahamsen 1972; Bengtsson et al. 1983; Terhivuo 1989) will also gradually disappear. Though there is no evidence for the existence of a 2–4 species community in the study area before the anthropogenic acidification took part, it is likely that the degradation of the forest soil is an important reason for the simplified 'one-species earthworm community' that was met on the first sampling occasion.

Third, over the last 100 years, since Darwin (1881), the occurrence of available calcium in the soil and its impact on the well-being of lumbricids has been discussed. In this context, attention has been drawn to the presence and function of calciferous glands in different earthworm species (see e.g. Jamieson 1981; Lee 1985) and to the need for available calcium to meet the demands of earthworm metabolism (Laverack 1963).

On the basis of the above-mentioned it was hypothesized that the reaction of the lumbricid populations to amelioration would be the opposite to that to degradation: the communities would increase in species number, biomass and density (cf. Schauermann 1987). Considering the short generation time and the relatively high reproductive output of the surface living earthworm species, the lag-time would be short, approximately some few years. Though the netbag experiments established that founder units of *D. rubidus* and *L. rubellus* were able to sustain themselves at least over a short period of time (1–2 years) in the study sites whether limed or not, the field survey failed to unequivocally demonstrate a positive response of the populations to raised pH and increased amount of available lime.

An obvious drawback in the design of the general remediation programme was that comparisons could be made between two pairs of forest plots only. Moreover, the pairs were of different successional stages. Unfortunately, it was impossible to increase the number of pairs, as would have been desirable (see Hurlbert 1984). To overcome the weakness of the survey, the netbags were introduced.

As stated above, it was primarily assumed that the populations would quickly respond to the amelioration and shortly after liming appear at increased densities and with a lowered adult: juvenile ratio due to an increased reproductive output. The substantial increase of the soil pH of the humus layer, 1.2–1.4 pH units (Table 1), was unambigously not followed by these events, not even after a lag-time of seven years. Being acid-tolerant (Satchell 1955) *D. rubidus* most certainly ought to tolerate the soil pH after the liming of site B. The netbag

experiments indicated that soil pH after liming was not too low to permit either *D. rubidus* or *L. rubellus* to exist since they survived and reproduced also in the unlimed soil. The absence of these species and the so far undetermined lag-time in the development of the *D. octaedra* populations indicate that a positive reaction of the earthworm populations would not merely be a question of low pH and increased availability of calcium only.

If a positive response to liming in the development of an earthworm population demands improved litter quality and/or increased variety of the potential food resources, changes to follow would be evident after an unspecified lag-time. Despite the great efforts devoted to the study of earthworms since the days of Darwin (1881) understanding of the food selection of most common species is still too scanty. Judging from the results of the survey the failure of the *D. octaedra* populations to develop rapidly and the almost complete absence of *D. rubidus* and *L. rubellus* from limed sites may indicate long-lasting low litter quality or few alternative food resources. However, the founder units in the netbags survived and reproduced under prevailing conditions.

Production and hatching success of cocoons of *D. rubidus* and growth of hatchlings are lower at pH 4.5 (acidified soil) than at pH 6.5 (limed soil) (Bengtsson et al. 1986). Similar studies on *D. octaedra* have not, as far as I know, been published. Despite being amended the limed sites still had a fairly low soil pH (<4.5), which may lead to an overall low fitness. A field study focussing on reproductive output offers poor chances to detect a feedback of liming on earthworms as long as available methods (density estimates, adult: juvenile ratio) are as crude as they are. The use of netbags may be a step forward to gain better understanding of reproduction in the field. The technique must however, rely on thorough knowledge of dispersal and food selection of a given species to permit enclosed specimens to perform adequately over seasons and life-time.

Most often the forest ground is heterogeneous; minor depressions with relatively moist and thick litter layer may alternate with patches characterized by a thin surface litter layer. Soil physical and chemical properties may also vary over the ground creating a fragmented habitat composed by varying microhabitats or microsites. These may offer a lumbricid population, as well as other soil animal populations, a fair chance to persist in the habitat (cf. Enckell and Rundgren 1988) and may maintain a source population from which dispersers can successfully colonize non-populated intermediate areas that have changed positively. From the field survey it can not be concluded whether the populations were heterogeneously distributed over microsites. Besides, it is not even known whether the study period covered the time needed to follow the processes of successful dispersal and colonization. Likely the success of colonization depends on species, distance between recruitment site and colonization site, density of the given source population, the quality of the soil in the colonization site etc. Earthworm species differ in dispersal and colonization abilities. It is commonly agreed that species primarily inhabiting the top soil (such as *D. octaedra*, *D. rubidus*, *L. rubellus*) generally have a higher dispersal ability than deep burrowing ones (*L. terrestris*, *A. longa*). From experiments introducing earthworms in virgin soils, dispersal rates of 4.5 m (*L. terrestris*; Hoogerkamp et al. (1983)) to 6–10 m year^{-1} (*A. caliginosa*; van Rhee (1969), Stockdill (1982), Hoogerkamp et al. (1983)) have been reported. But there is also evidence that dispersal in forest sites may be a slow process. Haimi (1993) introduced the deep-burrowing *Aporrectodea velox* (Bouché) and found that the population remained in a strongly restricted area. After six years the population was still found only 3–4 m from the point of release. (For a low rate of spread over the first 4–5 years after introduction, see also Stockdill 1966, 1982). Though few reports on dispersal ability of lumbricids are found in the ecological literature, there are indications of slow rates of dispersal and colonization in forest habitats and in amended soil. Satchell (1980a, b) reported on a study of earthworm populations in plots where birch was tested as the soil improver of a *Calluna* podzol. The difference in earthworm density between the samplings carried out when the plots were laid out and 27 years later fell within the limits of the year-to-year variation that normally is encountered in earthworm populations. This result points to a relatively long lag-time in the development of earthworm populations.

However, both Huhta (1979) and Persson et al. (1987) showed that the populations of different earthworm species increased over time after liming (in the case of Huhta (1979), also after the application of leaf litter). Both studies were based on small blocks: 3×3 m and 10×10 m, respectively. The positive findings could be due to liming *per se*, but attention should also be paid to the alternative interpretation that there is a dispersal from adverse or less habitable blocks to improved, bordering ones (i.e. redistribution) that may be reflected in increased abundance figures. Recently it has been shown that lumbricids may creep over rather long distances (Mather & Christensen 1992), which may influence the outcome of studies based on small-sized (in relation to dispersal ability) blocks.

There are reasons to believe that at least in soils of vast coniferous forests devoid of strong lumbricid populations liming only is not enough to obtain a rapid and positive response of the earthworm community. Likely successful colonization of species that have gone extinct due to acidification could be speeded up if the liming is combined with a simultaneous inoculation of earthworms typically found in the forest soil (see Huhta 1979). Since the liming experiment started, new light has been thrown on the allozyme variation of two of the species involved in the present study. Enckell et al. (1986) demonstrated that there is a significant genetic variation in populations of the sexually reproducing *L. rubellus* on the Faroe Islands. Similar findings concerning local populations of the parthenogenetic *D. octaedra* in Finland have been published by Terhivuo and Saura (1990). In the netbag experiments I used founder populations sampled in an area some 150 km from the experimental sites. Despite this, the founder units of at least *D. rubidus* performed well in the netbags. On the basis of the recent knowledge of genetic variability of lumbricid earthworms, it seems, however, reasonably that specimens used for inoculation should be selected from source populations of sites geographically close to and from habitats similar to experimental ones.

The present study focussing on the impact of liming of coniferous sites in southern Sweden did not unambigously reveal that an improvement of the soil is followed by a rapid and positive response of the lumbricid community. The four sites studied were primarily selected for an investigation of the impact of liming on soil chemistry and transport of Ca and not for a study on soil fauna. To obtain a more reliable picture of the effect of liming on earthworms more sites (to avoid pseudo-replication), longer study period (to follow slow processes, but see Satchell (1980a, b)), and less crude methods (to separate countermeasure-dependent changes in community parameters from natural temporal fluctuations) are needed. To overcome some of these problems, both laboratory (dispersal ability, impact of Ca on population parameters) and field experiments should be considered. Here the experiment with netbags indicates that some species absent at the start of the survey might be able to inhabit limed sites were they able to disperse to a given site and within it. In addition studies on colonization ability of inoculated earthworm species potentially inhabiting conifer soils and collected in similar habitats should be carried out.

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